Rangeland cattle production and the greenhouse effect, a review

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For years, scientists have been discussing and reviewing an important environmental issue, the greenhouse effect. Ruminants produce methane (CH_4), a colourless, odourless, nonpoisonous gas (The Merck Index, 1989) and this has made them targets of environmental concern.

Approximately 3.6% of Canada's land mass is used for grazing and forage production (Horton 1994). Of the 36 million ha in forage production, 26 million ha is native rangeland, 4 million ha is in cultivated pastures and 6 million ha is in forage crop production, compared to 25 million ha in grain and other mono-culture crops (Statistics Canada 1996). For this paper, Western Canadian rangelands and their beef production systems will be evaluated. The Prairie Provinces encompass approximately 60% of Canada's rangeland area and 76% of its cultivated pastures (15,721,000 ha of rangeland and 3,159,000 ha of cultivated pastures, respectively) (Statistics Canada 1996). Alberta, Saskatchewan and Manitoba contain 65.6% of the 13.2 million head of cattle in Canada (37.7, 18.4, and 9.5% of the total Canadian cattle population in Alberta, Saskatchewan and Manitoba, respectively; Statistics Canada 1998). It is crucial to determine if a pasture system supporting cattle is a net producer or net consumer of greenhouse gases.

The Greenhouse Effect

The key gases associated with the greenhouse effect include: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Council for Agricultural Science and Technology 1992: American Society of Agronomy 1993; Cicerone and Oremland 1988). Without the energy absorptive gases the average surface temperature of the earth, which is 15°C, would drop to -18°C (Schneider 1989). It is the

enhancement of these gases that causes the warming effect. To compare the different greenhouse gases two important points must be considered. First, the different gases have distinct residency times or decomposition rates in the atmosphere. Secondly, the emission of one gas may affect the level of the other gases, therefore, each gas will have different relative contributions to the warming effect (Rodhe 1990).

The carbon cycle is an important system that has many storage sites in the environment. Carbon (C) resides in soil organic matter, living creatures, the atmosphere, soil and plant biomass; all are important forms of C storage. For the purpose of this C cycling review, the main gases of interest are CO_2 and CH_4.

Carbon Dioxide

In 1994, the atmospheric concentration of CO_2 was estimated to be 370 ppmv (Tolbert and Preiss 1994) with a rate of increase of about 0.5% per year (Rodhe 1990; Tolbert and Preiss 1994). Carbon dioxide is estimated to contribute 50 (Ramanthan 1989), 60 (Rodhe 1990) or even up to 80% (Lashof and Ahuja 1990) of the global warming effect. The different values concerning the importance of CO_2 as a greenhouse gas, may reflect how the scientists categorize its absorptive effects. Anastasi et al. (1990) modeled future CO_2 emissions due to the burning of fossil fuels and estimated the atmospheric concentration will rise to between 415.4 and 420.7 ppmv by the year 2025. Approximately 40% of the CO_2 emissions remain in the atmosphere and the remainder of the gas is taken up by the oceans and land ecosystems (Tolbert and Preiss 1994).

Carbon dioxide has a residency time from 120 to 230 years (Lashof and Ahuja 1990; Rodhe 1990). The atmospheric residency time of CO_2 is very complex, rather than being destroyed, ÇO is transferred into other reservoirs (plant material on land and in the oceans) from which it can be

returned to the atmosphere. Therefore, CO_2 removal cannot be characterized by a single residence time.

Methane

In 1993, the atmospheric concentration of CH_4 was estimated at 1.7 ppmv (Anastasi and Simpson 1993) and is increasing nearly 1% per year (Rodhe 1990; Denmead 1991; Rasmussen and Khalil 1984; American Society of Agronomy 1993; Anastasi and Simpson 1993). Methane remains in the atmosphere for about 14.4 years, compared to 230 years for CO_2, this seems like a short period of time. However, in the atmosphere CH_4 is oxidized into H_2O and CO_2 which adds to the atmospheric CO_2 pool (Lashof and Ahuja 1990; Cicerone and Oremland 1988).

Methane has a strong absorptive capacity in the infrared portion of the electromagnetic spectrum (Rogers and Whitman 1991) and specifically at 7.7μm, a wavelength at which no other atmospheric gases are strong absorbers. The absorptive potential of CH_4 can vary significantly depending on the scientist's estimation. Differences occur if it is calculated on a weight basis or molecular basis and if residency times and concentrations are taken into account. Kiehl and Dickinson (1987) derived formulas to identify CH_4 as being 25 to 30 times more effective as a greenhouse gas compared to CO_2 on a per-molecule basis. Their equations were based on the ratio of infrared absorption and mean residence time. However, on a weight basis, 1 g of CH_4 will absorb 70 times more long-wave radiation than 1 g of CO_2 (Rodhe 1990; Ramanathan et al. 1988).

Methane accounts for 9.2 to 18% of the global warming effect depending on the scientific article that is referenced (9.2 % Lashof and Ahuja 1990; 18 % Pearce 1989; Ramanathan 1989; 15 % Rodhe 1990). In 1974, Ehhalt estimated that 80% of CH_4 originates at the earth's surface from anaerobic decay of organic matter, much of which is produced by natural wetlands.

Methane, indirectly produces an additional effect because a product of its oxidation in the atmosphere is CO_2 (Cicerone and Oremland 1988; Drennen and Chapman 1991; Desjardins 1991; Vaghjiani and Ravishankara 1991). Cicerone and Oremland (1988) calculated that atmospheric CH_4 would contribute about 6 % of anthropogenic CO_2 sources. Methane oxidation produces approximately 0.8 giga tonnes (Gt; 1 billion metric tonnes or 1 trillion kilograms) of carbon monoxide (CO) yr^{-1} (Logan et al. 1981). Within the following two to three months, the CO is converted to CO_2, therefore, about 0.34 Gt C yr^{-1} as CO_2 from CH_4 oxidation is produced globally (Cicerone and Oremland 1988).

Sources of Methane

Methane is produced by anaerobic bacteria called methanogens (Large 1983). These microorganisms are strict anaerobes and require high reducing conditions. The main sources of CH_4 in Canada include, natural wetlands, landfill sites, coal mining, fuel combustion, natural gas leaks, sewage storage, biomass burning, forest fires and large animals (domestic and wild). Natural sources account for 86.8% of CH_4 emissions and 13.2% of the emissions are from human associated activities (Jacques 1991).

Ruminant Methanogenesis

The percent of CH_4 lost, expressed as a fraction of the ruminant animal's dietary gross energy intake (GEI), decreases as the daily intake increases. Diet digestibility is negatively correlated to energy loss as CH_4 (Branine and Johnson 1990). Methane yield decreases as the concentration of dietary energy in the ration increases (Johnson et al. 1993b; Fahey and Berger 1988). The actual quantity of CH_4 produced may increase due to greater amounts of fermentable substrate in the rumen, although the percent of CH_4 energy lost as a percent of GEI declines (Johnson et al. 1993b). For a complete review of ruminant methanogenesis refer to the publication by McAllister et al. (1996).

Sinks of Methane

Carbon has many environmental sinks, including the soil organic matter, above ground vegetation and the atmosphere. The largest sink of CH_4 is the photochemical oxidation of CH_4 by the hydroxyl radical (OH) in the troposphere and stratosphere layers of the earth's atmosphere (Denmead 1991; Cicerone and Oremland 1988; American Society of Agronomy 1993; Vaghjiani and Ravishankara 1991; Crutzen et al. 1986; Ehhalt 1974). The size of this CH_4 sink is estimated to be 0.4 to 0.6 Gt yr^{-1} (Pearman and Fraser 1988 cited in Denmead 1991).

The total global flux of CH_4 is estimated to be 0.54 Gt CH_4 yr^{-1} with 85% of the flux oxidized in the troposphere ($CH_4 + OH \rightarrow {}_2H\,O + {}_2CH$), producing ${}_2CO_2$, $H\,O$, C_2O, H with various other intermediates. These oxidation reactions increase tropospheric and stratospheric ozone (O_3) amounts (tropospheric ozone is a greenhouse gas) and produce important quantities of H_2O in the stratosphere (Cicerone and Oremland 1988). In the stratosphere, almost all remaining CH_4 is destroyed by OH, chloride (Cl) atoms and by electronically excited oxygen atoms [$O(^1D)$]. When CH_4 binds with Cl this reaction potentially destroys important O_3 and puts chloride into a temporary reservoir (Stolarski and Oremland 1974). A very small fraction of CH_4 reaches the mesosphere (additional sink) and very short wavelength uv light destroys the CH_4 photochemically (Cicerone and Oremland 1988).

There is concern that the atmospheric OH sink of CH_4 is limited or decreasing (Denmead 1991; Cicerone and Oremland 1988). Hydroxyl radical levels may decrease in the atmosphere due to increased CH_4 concentrations and increased competitive CO concentrations. For a more complete review of the atmospheric oxidative reactions refer to the paper by Cicerone and Oremland (1988).

Carbon Cycling Through a Grassland System

Proper grazing stimulates an increase in grassland productivity and improved health of the stand. The cattle on pasture consume plant material and return it as waste for nutrient recycling (Trottier 1992). The key word is recycling, grazing cattle do not use fossil-fuel C, but C that at one time came from the atmosphere and was used by plants in the form of CO_2 (Drennen and Chapman 1991). Evaluating C flows through a grassland system can be very complex. However, for the purpose of this paper, the primary C movements and how the system is influenced by incorporating a grazing beef animal will be evaluated to determine if the system is a consumer or producer of greenhouse gases. The following calculations and equations were all obtained from the vast body of scientific literature and incorporated to create C flow tables.

Carbon Model Description

Cow Parameter Calculations

To evaluate the grazing system and the flows of C associated with it, a hypothetical or simulated cow was derived based on factual production parameters. A medium-framed, 475 kg cow (average weight over one year), calves in March and from May 25 to September 21 the cow and her calf graze a native mixed prairie rangeland (120 days of grazing). The cow is rebred on May 21 and no net weight gain is expected of the cow.

To determine the amount of C that flows through the cow, the amount of C ingested must first be calculated. Lusby et al. (1976) determined that a lactating cow grazing native range would consume 99 g kg^{-1} $W^{0.75}$ of forage dry matter (DM).

During the grazing season the 464 kg (average weight during the grazing season) cow's average DMI is 9.92 kg. The amount of C contained in plant material is approximately 45% of the DM (Barbour et al. 1987), consequently, the cow consumes 4.46 kg forage-C d^{-1}.

Cow Eructated Methane Production

To determine the amount of energy lost in the form of CH_4, prediction equations derived by Johnson et al. (1993b) were utilized. The percent CH_4 of gross energy intake (GEI) for a lactating mature cow on a 80-100% forage diet, can be determined by the following equation:

$$CH_4\% \text{ of GEI} = 5.50 - 2.25(\text{LOI}) + 0.06(\text{DE}) \quad [1]$$

where LOI is the level of intake (as a multiple of maintenance) of the lactating cow and DE is the percent digestible energy of the diet. Johnson et al. (1993b) suggested that the LOI of a lactating cow is 1.5, or 1.5 times her maintenance requirement intake. The simulated cow's LOI was 1.4; calculated from the net energy of maintenance (NE_m) required by the cow (9.91 Mcal/d; National Research Council 1996) and the net energy (NE) provided from the diet (13.79 Mcal/d). To use the CH_4 yield prediction equation, the gross energy (GE) of the diet must be calculated using the GE equation (Nehring and Haenlein, 1973 in National Research Council, 1984) :

$$\text{GE (kcal 100 g}^{-1}) = 4.79(\text{crude fibre, \%}) + 9.5(\text{ether extract, \%}) + 4.03(\text{nitrogen free extract, \%}) + 5.72(\text{crude protein, \%}) \quad [2]$$

The climax community of the rangeland includes, 45% Big Bluestem (*Andropogon gerardii*), 40% porcupine grass (*Stipa spartea*), 5% June grass (*Koeleria cristata*), 5% Little Bluestem (*Schizachyrium scoparium*) and 5% Side-oat grama (*Bouteloua curtipendula*).

The gross energy provided by each plant species is calculated in table 1. For the grazing beef cow in this model, 5.92 % GEI is lost as CH_4. The total GE of the cow's diet is 42.16 Mcal d^{-1} ; therefore, 2.50 Mcal of energy is lost as CH_4 d^{-1} or 0.19 kg CH_4 d^{-1}.

Cow Fecal Methane Production

The amount of feces produced by the grazing animal can be calculated by the following equation (National Research Council, 1996):

$$\text{Fecal Production (kg d}^{-1}) = \text{DMI}*(1-\text{DMD}) \qquad [3]$$

Where, DMI is the dry matter intake of the animal, and DMD is the dry matter digestibility of the diet (table 1). Carbon makes up about 45% of the fecal matter produced, assuming that feces DM is predominately plant material.

Lodman et al. (1992) stated that less than 1% of the CH_4 producing potential of feces is achieved on a grazing system, due to the drying of the fecal matter. To calculate the amount of CH_4 that fresh feces can emit, the amount of volatile solids (VS) in the feces must be determined.

$$\text{Fecal VS} = \text{kg fecal DM} * 0.81 \qquad [4]$$

(Lodman et al. 1992). After, approximately 2 days the feces will dry out, therefore, when calculating the amount of CH_4 produced by fecal matter on pasture, methanogenesis terminates after 2 days. Fresh cattle feces dries to below 30% moisture in less than 40 hours on pasture and minimal volatilization occurs (Buford and Varani 1976 in Lodman et al. 1992). Methane loss is related to the fraction of VS in fecal DM, with an estimated loss of 1 % of the volatile solids in the DM of freshly excreted feces as CH_4 (Lodman et al. 1992).

$$\text{kg Fecal } CH_4 \text{ } d^{-1} = (\text{Fecal VS})\ (0.01) \qquad [5]$$

The DMD of the cow's diet is 59.51%, therefore, 9.92 kg of forage DMI would produce (using equation 3) 4.02 kg of fecal DM. The amount of C in the feces would be 1.81 kg-C and the amount of VS (equation 4) would equal 0.033 kg CH_4 d^{-1}.

Cow Eructated Carbon Dioxide

Large (1983) stated that gaseous products of biodegradation in the rumen are 60 to 70% CO_2 and 30 to 40% CH_4. This supports earlier work by Hungate (1966) who observed that approximately 65% v/v of the eructated gas is CO_2 and minute quantities of hydrogen sulfide (H_2S), nitrogen (N_2) and hydrogen (H_2) gas. By difference, 35% of the eructated gas is CH_4, therefore, if the volume of CH_4 produced per day has been determined then the amount of CO_2 can also be calculated.

$$CO_2\ l\ d^{-1} = CH_4\ l\ d^{-1} * 0.65/0.35 \qquad [6]$$

When reviewing different scientific papers it is important to calculate CH_4 levels in the same units. There are 7.168×10^{-4} kg of CH_4 l^1 and the energy content of 1 kg of CH_4 is equal to 13.3 Mcal (Leith 1975 in Crutzen et al. 1986).

Based on the estimates of gas production by Hungate (1966), if the cow produced 0.19 kg CH_4 d^{-1} or 196.00 l CH_4 d^{-1}, and this amount of CH_4 represents 35% of the total gas eructated, then 65% or 364.00 l CO_2 would be produced per day. The density of CO_2 is 1.976 g l^{-1} (The Merck Index 1989), therefore, 0.72 kg of CO_2 is eructated per day.

Cow Fecal CO_2 Production

When fecal matter is deposited on a grassland, the feces will begin to decompose and CO_2 is released. The amount of CO_2 produced by the feces can be estimated by using the amount of C in the fecal DM (equation 3). Approximately 0.01% of the manure is decomposed per day (Barbour et al., 1987), assuming a similar decomposition rate as plant biomass.

Daily fecal excretion by the cow is equivalent to 1.81 kg-C which can be converted to 6.64 kg CO_2 if all fecal C was converted into CO_2. Given a decomposition rate of 0.01% d^{-1}, the following equation can be used to estimate the amount of fecal CO_2 produced over 210 frost free days in western Canada (Environment Canada 1998).

$$\text{Fecal } CO_2 \text{ production during grazing season} = FTA_{co2}[1-(1+i)^{-n}] \quad [7]$$

Where FTA_{co2} is the total amount of CO_2 that would be produced if all the fecal C was decomposed; i is the rate of CO_2 emitted from the feces and n is the number of days CO_2 is released from feces on pasture. During the grazing season, the cow produces 482.84 kg of feces (equation 3) with a C content of 217.28 kg, if all the C was available to decompose, 796.68 kg CO_2 would be produced, however only 0.01% CO_2 is emitted daily. Equation 7 discounts a 0.01% loss of CO_2 per day, therefore, 16.56 kg CO_2 is emitted from fecal decomposition during the 210 frost free days and 9.46 kg CO_2 during the 120 d grazing.

Cow Respiratory Carbon Dioxide

Direct measurement of CO_2 production by the grazing animals is very limited, therefore, a C-balance table was prepared (table 2). Sanchez and Morris (1984) measured the amount of CO_2 produced by grazing cattle, 3034 l CO_2 d^{-1} or 5.99 kg CO_2 d^{-1} was produced. When using the C-balance tables, 5.78 kg CO_2 d^{-1} was respired by the grazing cow, assuming that the amount of C the animal ingests will equal the amount of C expelled plus any C that is retained for growth or gain.

Carbon Content of Milk

Milk from a beef cow is composed of, on average, 3.59% fat, 3.38% protein, 4.95% lactose, (Marston et al. 1992) 0.8% ash and 87.28% water (Swenson 1970). To determine the amount of C in milk fat, the %C in fats ranging from C4 to C14 (Swenson 1970) were calculated using molecular

weight percentages, therefore, milk fat is made up of approximately 74.7% C. The amino acid C content of milk protein was calculated, thus, milk protein is about 45.6% C. The primary carbohydrate in milk is lactose ($C_{12}H_{22}O_{11}$), which is made up of 42.1% C.

Le Du et al. (1976) studied milk and grazed forage intake of suckling calves on pasture. They found that as milk production decreases, the calf will increase its forage intake and duration of grazing. Milk dry matter intake (MDMI) and forage dry matter intake (FDMI) was calculated by using the calf's weight everyday for 120d grazing, multiplied by the intake level of each component presented in table 5 The average amount of FDMI and MDMI was 1.86 kg d^{-1} and 1.40 kg d^{-1}, respectively. A total of 1305.3 kg of liquid milk or 172.3 kg milk DM was consumed by the calf during the grazing season.

Each milk component (fat, protein and carbohydrate) is multiplied by the milk yield and the percent C that each contains to determine the amount of milk C produced by the cow. The 1305.3 kg of milk contains 35.00, 20.12, and 27.20 kg of C from the milk fat, protein and lactose. Overall, 82.32 kg C was expelled in the form of milk constituents.

Carbon in Fetal Gain

During gestation the cow will gain weight via fetal tissue gain; therefore, C is retained by the cow. Data on cow and fetus weight gain over gestation (Brody 1964) indicated a ratio of fetus weight gain to cow weight gain estimated at 0.57. For a calf with an average birth weight of 40.5 kg (n=86, Marston et al. 1992), the cow gains 40.5 kg in fetal tissue and 23.2 kg of body weight, for a total of 63.7 kg of weight gained over gestation. However, approximately 25% of the fetal weight gain occurs during the first two trimesters (188 d) (Alberta Beef and Sheep Branch 1989). Therefore, only 10.13 kg of fetal gain occurs during the 120 d of grazing. Hafez and Dyer (1969), estimated that a

calf is approximately 78% water, thus, the fetal tissues weigh 2.23 kg on a DM basis. On average, a calf is composed of 26.5% bone, 8.5% fat and 65% muscle (Hafez and Dyer 1969). There is 0.004 kg bone-C, 0.14 kg fat-C and 0.16 kg muscle-C, for a total of 0.30kg of fetal-C. Refer to table 3 for the %C of each body tissue constituent.

Hafez and Dyer (1969) showed that 51% of the cow's weight gain during gestation is made up of added membranes and the remaining 49% is fluid weight gain. Therefore, of the 23.2 kg of cow gain, 11.94 kg is membrane tissues and 11.26 kg is fluid. The membranes developed during gestation are primarily made up of protein, hence, 45.6% of the membrane is C or 5.44 kg of C is contained in the cow's weight gain.

Calf Parameters and Calculations

The simulated calf weighs 40.5 kg at birth and is expected to achieve an average daily gain (ADG) of 1.14 kg d^{-1} on the mixed prairie rangeland. The calf would be 86 days of age and 140.8 kg at the beginning of the grazing season and is weaned at the end of the grazing season at 205 d of age weighing approximately 281.02 kg.

The amount of forage-C consumed by the calf is calculated in the same manner as that of the calculations for the cow. The average FDMI over the grazing period is 1.86 kg d^{-1} and the average amount of MDMI is 1.40 kg d^{-1}. The total amount of milk consumed by the calf is 1305.3 kg, containing 82.32 kg of milk-C.

Calf Eructated CH_4 Production

To determine the amount of energy lost in the form of CH_4, for a growing calf the following equation by Johnson et al.(1993b) can be used:

$$CH_4\% \text{ of GEI} = 11.33 - 1.81(LOI) - 0.02(DE) \quad [7]$$

where the LOI for the calf is 1.7. Table 4 presents the amount of each plant species the calf consumes and the amount of energy in the calf's daily forage intake.

The assumptions and calculations for eructated CO_2, fecal CH_4, fecal CO and other C flow components are calculated in the same manner as those calculated for the cow (table 6).

Carbon Retained in Calf Growth

As an animal grows and develops, the percent muscle, bone and fat vary with age. Using relative growth curves from Forrest et al. (1975) the percentages of the deposition of muscle, bone and fat were obtained. For a calf of 4 months of age, representing the mid-point of the grazing season, 14.3% of the weight gain is muscle, 1.87% is fat and 5.83% is bone. The average daily gain of the calf is 1.14 kg d^{-1}; the amount of C in the calf gain is determined by calculating the amount of C in each of the components gained (table 3). Swenson (1970) stated that 78% of the calf's weight gain is water.

Carbon of muscle

Estimation of %C in muscle, is more complex than bone or fat because muscle is composed of 18.5% protein, 3% fat, 1% glycogen, 1% non-protein nitrogenous compounds and 1.5% inorganic elements (Forrest et al. 1975). For a final estimate of C in calf muscle gain, protein contains 45.6% C, fat 72.1% C and glycogen 44.4% C, thus, the amount of muscle gain can then be broken down into each of its components and multiplied by the component C content. Therefore, on average muscle is made up of 11.04%C.

Carbon in Fat Gain

Bovine fat is primarily made up of triglyceride molecules containing one molecule of palmitic acid and 2 molecules of oleic acid attached to a glycerol molecule (Forrest et al. 1975). The second most

abundant triglyceride in bovine fat is one molecule each of palmitic and stearic acid attached to a glycerol molecule (Forrest et al. 1975). The molecular weight of the constituent fatty acids will determine the %C in the triglyceride. An average C% of the two most abundant triglycerides is 72.1% C, which multiplied by the total amount of fat gained by the animal will equal C retained via fat deposition.

Carbon in Bone Gain

Calcium and magnesium are the main components of bone and the only component that contains C is carbonate (3.5% CO_3)(Swenson 1970). Therefore, bone is 0.7% C and the remaining components include calcium, magnesium and sodium.

Carbon Flow in Plant and Soil Systems

Carbon Storage in Grasslands

The amount of C that a grassland system can assimilate or consume may vary due to many factors. If a grassland is left undisturbed the amount of C stored in this system will equilibrate (Stevenson 1986; Van Veen and Paul, 1981). Steady state levels of organic matter (C) in the native rangeland requires a return of CO_2 to the atmosphere via soil respiration in amounts equal to gains by photosynthesis and therefore, the content of OM in any given soil remains essentially constant from year to year (Stevenson 1986) . As well, Van Veen and Paul (1981) reported that soil OM levels in equilibrium are more dependent on the decomposition rate and amount of resistant humic matter present in the soil, than decay rate of added residues. Therefore, year to year grazing may not have a significant effect on C storage in the short-term. Resistant OM in the soil has a greater overall affect on total soil C storage. An estimate of the quantity of C returned to the atmosphere as CO_2 from the plant biomass, can vary yearly, depending on the crop grown, climate, environment and

other physical factors. It is conceivable that CO_2-C and CH_4-C released by the animal could be assimilated by the plant-soil C storage system. The system retains the potential of C storage capacity. In a worst case scenario, if the plant biomass is not encouraged to increase above and below ground productivity with grazing, for example during extreme water stress or overgrazing, the loss of soil C storage (table 7) would be in the range of 13.1%.

Grazing and Carbon Storage

The manner in which the grassland is grazed is very important, continuous grazing may not encourage plant growth, in fact, over grazing can be detrimental to the plants and the condition of the grassland. In extremely arid regions grazing may decrease plant productivity (Kumar and Joshi 1972). However, with suitable grazing management, rangelands situated in moist and sub-humid climates can increase above ground productivity (Aldous 1930; Biswell and Weaver 1933; Peterson and Hagen 1953, Sims and Singh 1978) as in the current model's sub-humid climate. The reason for increased production is due to the regrowth of grazed plants enhanced by reduced shade from standing dead plant material (Sims and Singh 1978 b) and maintaining the plants in a vegetative state.

Above Ground Biomass Productivity

Above ground biomass production depends on the type of pasture grazed. For example, Sims and Singh (1978 a,1978b) found annual above ground primary production of tallgrass prairie in Western North America to increases 25 to 31% when it was grazed relative to ungrazed treatments. Mixed grass prairie above ground primary production also is enhanced when subjected to grazing (Kelting 1954; Duvall 1962). Assuming above ground biomass production will increase by 25% with grazing, approximately 555.5 kg DM ha^{-1} more forage would be produced from the original 2222 kg DM ha^{-1} in our model.

Below Ground Biomass Productivity

Below ground or root production may also increase due to grazing. The annual net root production was 21% greater when grasslands were grazed (4350 kg DM ha^{-1}) compared to ungrazed plots (3420 kg DM ha^{-1}) (Sims and Singh 1978b). Root biomass production increases as the long term annual temperature decreases (Sims and Singh 1978b). Therefore, an additional 273 kg C ha^{-1} was estimated to be stored in the below ground biomass (21% of 1300 kg C ha^{-1} from root biomass) of the model grassland.

Decomposition and Assimilation of Carbon in a Grassland System

Equations for the decomposition and assimilation of C in a grassland system cannot easily be simplified for the current model. The best alternative is to utilize a previously proven model by Van Veen and Paul (1981). They validated their model using field data from a native mixed range located in the brown soil zone of southern Saskatchewan and measured the C content at 3 depths of soil; 0-15, 15-40 and 40-80 cm (table 7). This particular grassland produced 2000 kg of litter C ha^{-1} yr^{-1} and 1000 kg of the litter-C entered the soil that year (Van Veen and Paul 1981). The root biomass comprised approximately 40% of the total plant productivity (Warembourg and Paul 1977) and hence about 1300 kg root-C ha^{-1} yr^{-1} was stored into the grassland soil. The study did not appear to include a grazing animal, therefore the amount of C consumed by the grazing cow and calf were subtracted from the initial plant biomass produced and compared to the soil C data provided by Van Veen and Paul (1981).

The draw back of this situation is that with proper grazing management, above and below ground biomass may be stimulated to grow, as stated above. Grazing may decrease the aboveground biomass present at any point in time but it may not decrease the total annual biomass produced. Mixed grass

prairies that have been grazed have a larger proportion of their live biomass in the form of roots compared to ungrazed pastures (Sims et al. 1978). Sims and Singh (1978a, 1978b) found that under certain conditions mixed-grass prairie plant production had enhanced root growth under grazing compared to pastures that were not grazed. Data from their mixed prairie ranges showed an average increase in root biomass of 109.75 kg ha^{-1} or approximately 49.4 kg C ha^{-1} with continuous grazing..

Grassland Oxidation of Methane

Soil also has the potential to oxidize CH_4 by varying degrees. If the field is fertilized and dry, the potential for CH_4 oxidation decreases significantly (American Society of Agronomy 1993). However, if the field is in native pasture approximately 3.1 kg CH_4 ha^{-1} y^{1} will be consumed by the soil (Colorado native pasture). This value drops to 2.0 kg CH_4 ha^{-1} y^{-1}, as soon as manure fertilizer is added to the field (Mosier et al. unpublished data in Johnson et al. 1997). Therefore, over a grazing period of 120 days, about 1.02 kg CH_4 ha^{-1} is consumed by the native prairie.

Discussion and Results

The grazing animal returns a large proportion of consumed plant nutrients back into the soil and, therefore, pasture feeding represents a highly sustainable form of agriculture (Cohen 1992). The nutrient cycle from plants to soil continues; if you add a herbivore the nutrient chemical structure is changed and returned to the soil as feces and urine. Nutrients such as nitrogen and phosphorous from animal excreta are more readily available for plant use than nutrients that are simply recycled through the plant-soil interface (Cohen 1992). Schimel (1986) estimated that 30% of the C consumed by cattle is returned to the soil. From the C balance tables our model estimated that approximately 40% of the C consumed is returned to the soil (via fecal-C).

When comparing greenhouse gas equivalents (GHGE; based on CO_2) in tables 2 and 6, the GHGE of forage DMI is greater than the values emitted or produced by the animal during the 120 days of grazing. In other words, if all the forage the cow and calf consumed was degraded to CO_2, 2344.55 kg GHGE would be emitted. The summation of the cow and calf's GHGE for the long-term and short-term results in 1244.09 and 1892.69 kg GHGE, respectively. Thus, the grazing animals produce less GHGE enterically, than the native mixed rangeland's aerobic decomposition. Under the model parameters, the grazing cow-calf pair on 1 ha of native mixed prairie does not pose any environmental threat.

The C storing potential of a grassland may seem to decrease with grazing. However, C is also stored in the bodies of the grazing animals. In studies comparing grazed pastures to virgin prairie, researches may not take into account the C that exits the pasture in the from of animal weight gain and C released by the digestive process (Bauer et al. 1987). Of the total amount of C consumed by the cow calf pair (722.74 kg C), 1.36% of the C is removed from the system in the form of animal weight gain. The cow gains 5.74 kg C during gestation on pasture and the calf retained 4.06 kg C over 120 days grazing.

Grazing Compared to Cultivated Crops

Harvesting grass through grazing does not use fossil-fuel C. However, when cultivated crops are produced more C is emitted in the form of fossil-fuels. Entz et al. (unpublished data) determined C emissions from a series of different crop rotations including peas, wheat, flax and alfalfa. On average, 3941 kg of fossil-fuel C ha^{-1} yr^{-1} was emitted through the use of fuel, C to produce machinery, N-fertilizer, P-fertilizer and herbicides to plant and manage the different crops (Entz et al., unpublished data). For example, a 5 year alfalfa-wheat-wheat rotation produced on average 5918 kg of fossil-fuel

C ha^{-1} yr^{-1} with the alfalfa yielding (5 year average) 9048 kg DM ha^{-1} yr^{-1}, the mechanical harvest of the forage would remove 4071 kg C ha^{-1} yr^{-1} from the system (adapted from data in Entz et al., unpublished data). Whereas, the cow-calf grazing system does not emit fossil- fuel C and returns most of the C to the grassland system. It is easy to see how cultivation can decrease the amount of C stored in the soil and in the plant biomass.

Conclusion

Theoretically, the cow does not enhance the greenhouse effect under normal grazing conditions, no more than normal decomposition of the pasture forage. The duration of the current model is one grazing season (120 d), therefore, the precise effect the grazing animal has on C storage in the rangeland cannot be assessed directly. However with the data published by Van Veen and Paul (1978) an estimate of the rangeland C content can be characterized. The final results of such an evaluation would best be accomplished by using actual field data. However, a project of that magnitude would be very complex and require a very competent group of scientists from many disciplines. Further research is needed to directly quantify the amount of C in the grasslands of different regions and the effect of grazing these regions.